UNIVERSITI PUTRA MALAYSIA

NUMERICAL INVESTIGATION OF FIBRE ORIENTATION IN SHORT GLASS FIBRE REINFORCED INJECTION-MOULDED THERMOPLASTIC COMPOSITES

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By

EDI SYAMS ZAINUDIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of Requirement for the Degree of Master of Science

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To My Family

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

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Chairman: Assoc. Prof. Ir. Dr. Mohd. Sapuan Salit

The aim of this simulation work is to carry out a comparative study of the fibre orientation distribution (FOD) in the short glass fibre reinforced injection moulded thermoplastic (S_gFRIMT) composites. The objective of this research is to use a numerical method to investigate the effect of two significant parameters namely, speed of injection and thickness of specimen, on the FOD of the S_gFRIMT composites. The numerical simulation is conducted by Moldflow Plastics Insight (MPI) software. MPI software is used to investigate the flow behaviour and to examine the effects of processing conditions on the mouldings. Effects of the thickness of the specimen and injection speed are considered since they have great influence on the mechanical properties of the products.

The effect of the injection speed on the FOD is not significant in the thicker plaque. The difference of FOD between the 2 mm and 4 mm plaques has been reported and it was observed that thinner plaque received more aligned fibres at the flow direction due to higher shearing flow generated compared to the thicker one.

The fibre orientation is observed for variations from the skin to the core. In the skin the fibres are highly aligned in the flow direction, whereas in the core the fibres are mainly aligned in the direction transverse to the flow. The more the short fibres are aligned in the moulded parts the better the mechanical behaviour is. Higher injection speeds influence the fibres so as to align along the flow direction but decreases from the skin to the middle/core plane.

The overall result of executing the MPI program over the published results gives a full agreement upon the FOD in S_gFRIMT composites. The simulated results also agree with other published numerical works. These verify the use of MPI simulation method.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

PENYELIDIKAN BERANGKA BAGI PENGHALAAN GENTIAN TERHADAP KOMPOSIT PLASTIK HABA PENGACUAN SUNTIKAN BERTETULANG GENTIAN KACA PENDEK

Oleh

EDI SYAMS ZAINUDIN

Julai 2002

Pengerusi: **Prof. Madya Ir. Dr. Mohd Sapuan Salit**

Fakulti: **Kejuruteraan**

Matlamat penyelidikan penyelakuan ini adalah untuk membuat kajian perbandingan terhadap taburan penghalaan gentian (FOD) di dalam komposit plastik haba pengacuan suntikan bertetulang gentian kaca pendek (S_gFRIMT). Objektif kajian ini juga untuk menggunakan kaedah penyelakuan berangka bagi mengkaji kesan dua parameter utama iaitu, kelajuan penyuntikan dan ketebalan spesimen terhadap FOD bagi komposit S_gFRIMT ini. Penyelakuan berangka ini diselenggarakan oleh sebuah pengaturcaraan komersil iaitu Pengaturcaaran Moldflow Plastics Insight (MPI). Aturcara MPI ini digunakan untuk mengkaji kesan keadaan-keadaan pemperosesan terhadap pengacuan yang dihasilkan. Kesan-kesan ketebalan spesimen dan kelajuan penyuntikan diambilkira kerana mereka mempunyai pengaruh kuat dalam menentukan sifat-sifat mekanik sesuatu produk yang dihasilkan.

Didapati kesan kelajuan penyuntikan ke atas FOD adalah tidak begitu ketara terhadap plak yang lebih tebal. Perbezaan FOD dia antara kedua-dua cakera, 2 mm dan 4 mm telah dilaporkan dan didapati, cakera yang nipis

mempunyai lebih banyak gentian yang terbentuk sejajar dengan arah aliran suntikan. Ini disebabkan kesan daripada tindakan aliran ricih yang lebih banyak terhasil pada cakera berkenaan berbanding dengan cakera yang lebih tebal.

Penghalaan gentian sentiasa diperhatikan kesan perubahannya daripada dinding ke teras spesimen yang dikaji. Pada dinding, gentian adalah selalunya sejajar dengan arah aliran manakala pada teras, gentian-gentian biasanya bertentangan dengan arah aliran. Semakin banyak gentian yang sejajar dihasilkan di dalam pengacuan, semakin kuatlah sifat mekanik bahan yang dihasilkan. Kelajuan yang tinggi pada suntikan menyebabkan gentian akan bergerak sejajar di sepanjang arah aliran tetapi akan berkurangan kesejajarannya daripada dinding ke teras/tengah satah.

Akhirnya, keseluruhan keputusan kajian perbandingan yang menggunakan aturcara MPI berbanding keputusan-keputusan yang telah diterbitkan di jurnal-jurnal adalah sehaluan/sekata dalam menyatakan kesan FOD bagi komposit S_gFRIMT. Keputusan penyelakuan ini juga sehaluan dengan kerja-kerja penyelakuan berangka yang telah diterbitkan. Ini semua mengesahkan lagi kepenggunaan kaedah penyelakuan MPI ini.

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Great appreciation is also extended to colleagues and to all those who contributed directly or indirectly to the success of this study, may ALLAH bless them all.

I certify that an Examination Committee met on 31st July 2002 to conduct the final examination of Edi Syams Zainudin on his Master of Science thesis entitled "Numerical Investigation of Fibre Orientation in Short Glass Fibre Reinforced Injection-Moulded Thermoplastic Composites" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirements for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

EDI SYAMS ZAINUDIN

Date: 16 . 8 . 2002 .

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NOMENCLATURE

a_{ij}	Second order of orientation tensor
D	Fibre Diameter
E	Elastic modulus
E_m	Matrix modulus
FOD	Fibre orientation distribution
GFRPA	Glass Fibre Reinforced Polyamide
GFRPC	Glass Fibre Reinforced Polymer
GFRPE	Glass Fibre Reinforced Polyester
GFRPP	Glass Fibre Reinforced Polypropylene
C_I	Interaction coefficient
L	Fibre length
m	matrix phase
MPI	Moldflow Plastics Insight (MPI) software.
p	particulate phase
R_x, R_y	Effective radius in x and y direction
SFRP	Short-fibre reinforced plastics
S_gFRIMT	Short glass fibre reinforced injection-moulded thermoplastic
V	volume fraction
x,y,z	x,y,z coordinates

Greek Symbols

ω_{ij}	the vorticity (whirling)
γ_{ij}	deformation tensors

v_k	the velocity component
δ_{ij}	Unit tensor
ρ	Density
δ	Elastic deformation
η	Viscosity
θ	Fibre in plane angle
φ	Fibre out of plane angle

Subscripts

i, *j*, *k* Indices

Note: other symbols are defined in the text.

CHAPTER 1

INTRODUCTION

1.1 Overview

Short-fibre reinforced plastics (SFRP) are being widely used for technical and industrial applications due to their light weight, good mechanical properties, easiness of manufacturing and low fabrication cost. The increasing number of applications of short fibre composites makes it more important to understand and predict their mechanical and thermal properties, where these properties depend strongly on fibre orientation and volume fraction. The fibre volume fraction is usually known from the initial mixing ratio of fibre to matrix whereas the fibre orientations have to be determined numerically and experimentally since they are influenced by the fabrication process (Mlekusch, (1999) and Chung and Kwon (2000)).

Short fibre composites composed of reinforcing discontinuous fibre and polymeric matrix material. Injection moulding is one of the most productive way by which short fibre composites can be processed in high precision. However, due to complex flow pattern in the cavity, a certain orientation of fibres is likely to happen. This flow-induced fibre orientation results in anisotropy that affects mechanical properties as well as microscopic structure and final shape of the product (Gupta and Wang, 1993). To improve the properties of the part, it is necessary to predict the fibre orientation, which causes the anisotropy. Computational analysis of flow in injection moulding enables us to predict flow-induced fibre orientation and resulting anisotropy of the moulded part. Moreover, it is possible to predict other properties of the moulded part such as residual stress, bulk shear and stress, weld lines, air traps and final shape of the part. Predicted information must be very helpful for engineers in designing process conditions and geometries of the injection mould.

1.2. Objectives of the Research

The idea of this simulation work is to carry out a comparative study of the fibre orientation distribution (FOD) in the short glass fibre reinforced injection moulded thermoplastic (S_gFRIMT) composites. The aim of this research is to use a numerical method to investigate the effect of two significant parameters namely, speed of injection and thickness of specimen, on the FOD of the S_gFRIMT composites. The numerical simulation is conducted by Moldflow Plastics Insight (MPI) software. To achieve this aim, the following objectives are proposed:

- To compare the results arising from the MPI program with other published experimental findings.
- To analyse the effects of injection speed on fibre orientation.
- To analyse the effects of part thicknesses on fibre orientation.

1.3 The Significance of this Study

Prediction of the fibre orientation distribution in short glass fibre injection moulded thermoplastic composite is performed using the numerical simulation. MPI software is used to investigate the flow behaviour and to examine the effects of processing conditions on the mouldings. Effects of the thickness of the specimen and injection speed are considered since they have great influence on the mechanical properties of the products.

Short glass fiber-reinforced thermoplastic composites are becoming very popular in many application fields as a consequence of the possibility of combining the toughness of thermoplastic polymers with the stiffness and strength of reinforcing fibers. Moreover, the use of reinforcing short glass fibers can yield materials with a large variety of physical characteristics, depending on the type of the composite and processing conditions used for its preparation. Furthermore, the attainable lower weight due to their low density can produce a decrease of vehicles gas emission, thus enhancing the quality of life (Chung and Kwon, 2000).

1.4 Structure of the Work

The first chapter presents an introduction to short glass fibre reinforced injection-moulded thermoplastic (S_gFRIMT). This chapter also gives the objectives and the significance of the research. The structure of the study is given in Figure 1.1.

In the following chapter (Chapter 2), the literature related to S_gFRIMT composites and fibre orientation distribution (FOD) is reviewed in accordance with their importance and relevance. The experimental determination of FOD and the predicted works are also reviewed.

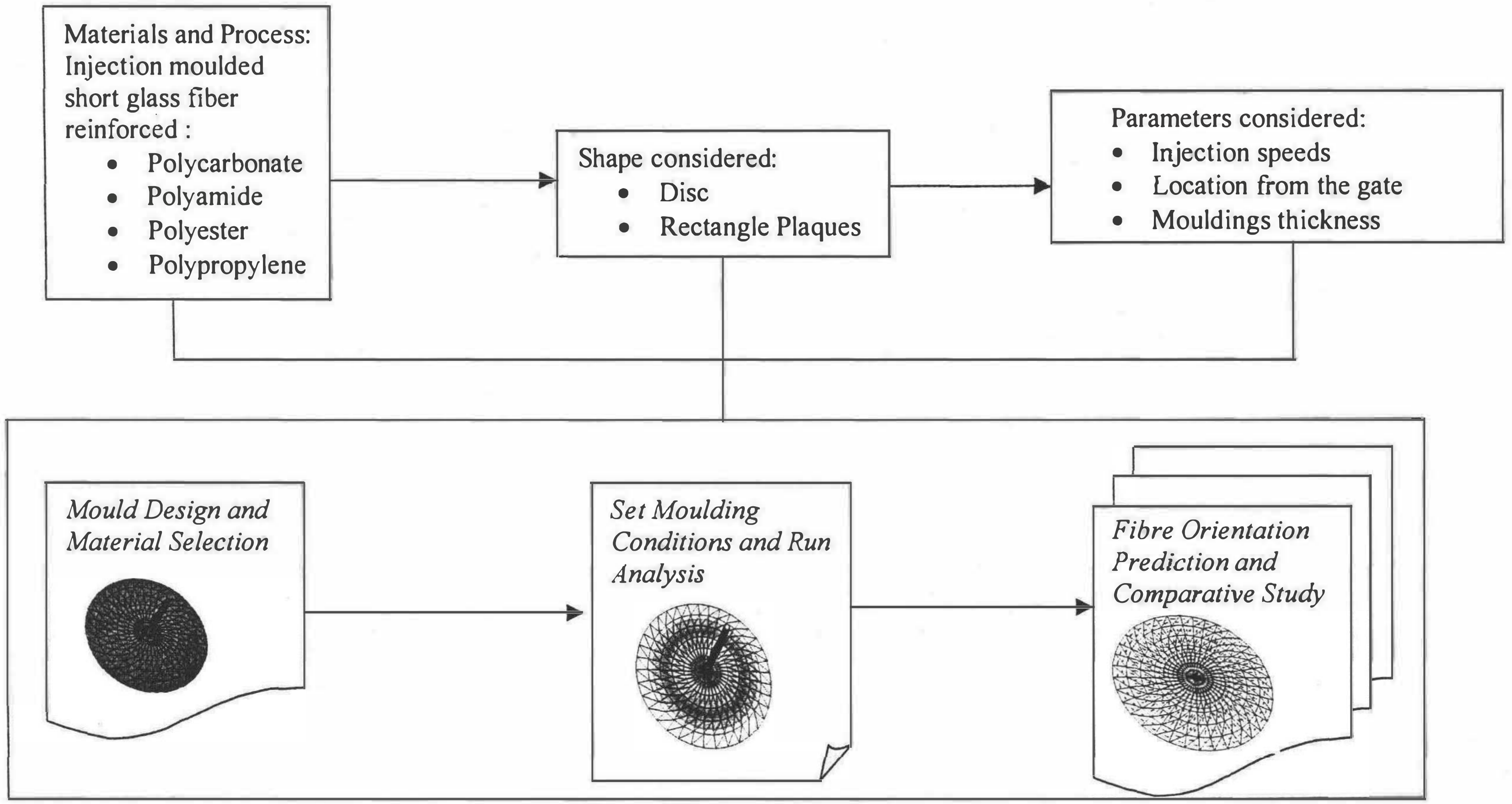

Figure 1.1: Overview of the structure of research programme